

DEVELOPMENT OF AN AUTOMATED SYSTEM FOR MANEUVERING PARABOLIC DISH ANTENNAS USED IN SATELLITE COMMUNICATION

Marcos César Rafael, satellite@cancaonova.com

Foundation João Paulo II – Department of Broadcasting
Rua João Paulo II, s/n – CEP: 12630-000 – Cachoeira Paulista, SP - Brasil

João Bosco Gonçalves, joao.goncalves@unitau.com.br

Pedro Paulo Leite do Prado, pplprado@ieee.org

University of Taubaté (UNITAU) – Department of Electrical Engineering
Rua Daniel s/n (Campus da Juta) – CEP: 12060-440 – Taubaté, SP - Brasil

Abstract. *The automation in all its aspects has become widespread and promises to represent the future for information technology, according to some researchers. This paper aims to present and discuss the results from the development of an automated system for maneuvering of the parabolic reflector antennas of a satellite communication. This work automates the key steps involved in the manual maneuvering of an antenna dish. Based on procedures for the manual maneuvering a satellite dish, was proposed an architecture that employs hardware solutions and software. It was added to the platform a GPS antenna to monitor the spatial location, and a digital receiver, which provides the value for the carrier-to-noise ratio, C/N. The main focus of this work was to design and develop in Java, a Control System Antenna Maneuvering, 3SA that can process the information of the spatial position of the antenna, generating a reference signal for a servo capable of processing the C/N and making a fine adjustment of the position of the antenna in order to improve signal reception. The user can select the desired satellite and monitor the process of automatic annotation, through a set of user-friendly graphical interfaces. In the context of this work, we found that even if the antenna is in a desired position, the C/N ratios should be above a minimum value for a good reception. Consequently, it was necessary to design a control system to fine-tuning the antenna position. Our approach in this case was to use a fuzzy controller which employed 63 rules, generated according to rules of thumb used in the process of manual maneuvering a satellite dish. This solution allowed for better placement of the antenna and therefore a C/N ratio above the minimum for good reception. The experimental results showed a perfect match for our approach to automate the key steps manual maneuvering an antenna dish.*

Keywords: *automation, object-orientation, antenna maneuvering, system development.*

1. INTRODUCTION

The maneuvering of satellite dishes is currently performed manually wasting many hours to perform this process. Basically, for the manual, we use a spectrum analyzer to monitor the signal during movement of the antenna until the desired satellite is found. Also, to look for the location of a satellite in order to achieve the best reception is an exhaustive process.

Figure 1 illustrates a professional application of parabolic antennas: a satellite communication system to send and receive TV, radio and internet. The parabolic antennas have a high cost, that depends on the diameter of the antenna. Since each antenna is dedicated to a satellite, it is difficult to point it. So, it is necessary an automated system in order to achieve the optimum positioning for reception of the signal.

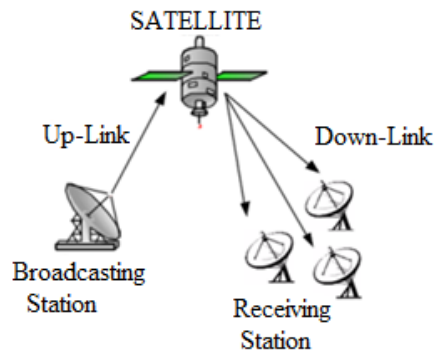


Figure 1 – Satellite communication system

Many works addressed the antenna control system realization.

Chang-ho, Sang-hyo (2003) developed a control method using an antenna step tracking algorithm with H_{∞} controller. This required to develop a discrete-time controller for the fast tracking of the satellite. The method applies the sample data control theory H_{∞} . The real-time controllers are implemented using the CEMTOOL software and the DSP/IO board (RG-DSPIO). Block algorithms are transformed into C codes by AUTOTOOLS in CEMTOOLS and downloaded to the DSP board in order to execute experiments. In implementing the step algorithm, it was verified that the performance of the antenna tracking system largely depends on step sizes through repeated experiments. The results of this work through samples of H_{∞} controller data, demonstrate the robustness of the method compared with the conventional PID controller.

Jongkwon et al. (2006) developed a method for controlling an antenna mounted on a vehicle. This required to design a fuzzy controller to control the tracking antenna. The method was developed from the stabilization of fuzzy rule-based tracking algorithm. With the stabilizing the tracking algorithm, the PID fuzzy controller was determined. The performance of the method was verified through simulations with Matlab[®] and Simulink[®] software. The data obtained were compared with the conventional PID controller. The result of this work indicated that the fuzzy PID controller has better performance than the conventional PID controller.

Our new approach address the key steps involved in manually maneuvering a satellite dish to generate design solutions called Automatic Antenna Maneuvering, S3A. Our method, S3A, incorporates a database containing information about the satellites available in our country, used for transmission in broadcasting. After the choice of a satellite, S3A generates the reference position for the antenna, which will be used by a servomechanism. S3A offers many user-guided-interfaces that provide information about the movement of the antenna toward the reference position, the spatial position of the antenna and the C/N ratio. After the antenna reaches the reference position, S3A monitors the quality of the reception through the C/N ratio. For a good reception quality, the C/N ratio must be at least 8 dB (HA, 1986). If this ratio is below of this value, the S3A realize the fine adjustment of the antenna position through servomechanism small movements around the beam width (Esteves, 1980).

2. TECHNICAL MANEUVERING MANUAL

Basically, in the manual maneuvering is necessary: a receiver decoder digital satellite set at a desired frequency, a spectrum analyzer; a C band parabolic antenna, coaxial cable, and RF signal splitter. Manual maneuvering the parabolic antenna to search for the location of a satellite is exhaustive processes to achieve a C/N ratio above a minimum value for a good reception.

The parabolic antenna is manually maneuvered in elevation an azimuth, using a compass and an inclinometer, respectively.

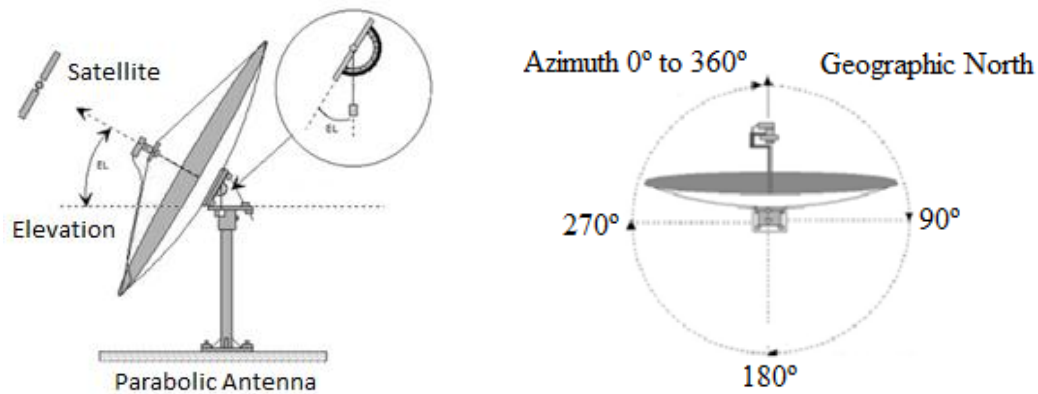


Figure 2 – Antenna elevation and azimuth angles

The phases of the alignment are:

- The antenna is aligned using the calculations of azimuth and elevation angles and observing the signal strength on the spectrum analyzer;
- The receiver provides a signal (control variable) proportional to the signal-to-noise ratio (SNR);
- This variable controls the antenna azimuth and elevation in order to achieve the best SNR.

3. MODEL AUTOMATIC MANEUVERING SYSTEM

Our solution comprises the following phases: to construct a database with information about the satellites available for transmission in broadcasting in Brazil, to calculate and generate the antenna reference position, which will be used by a servomechanism, to perform the antenna position fine adjustments through small servomechanism movements around the beam width, and, finally, to offer user-guided-interfaces that will provide information about the spatial position of the antenna and the C/N ratio.

Figure 3 shows the system architecture proposed for the automatic maneuvering of the satellite: a 3.2 m diameter antenna dish, a digital satellite receiver to decode the channels of the satellite and a GPS to determine the position of the antenna.

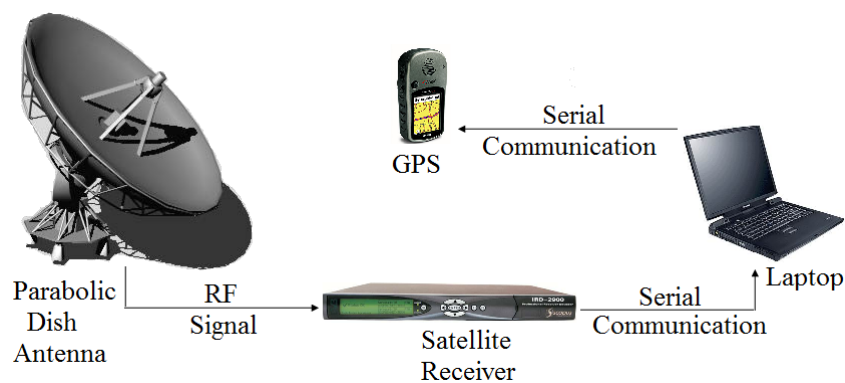


Figure 3 – Automatic maneuvering system.

Figure 4 is a flowchart of the S3A system.

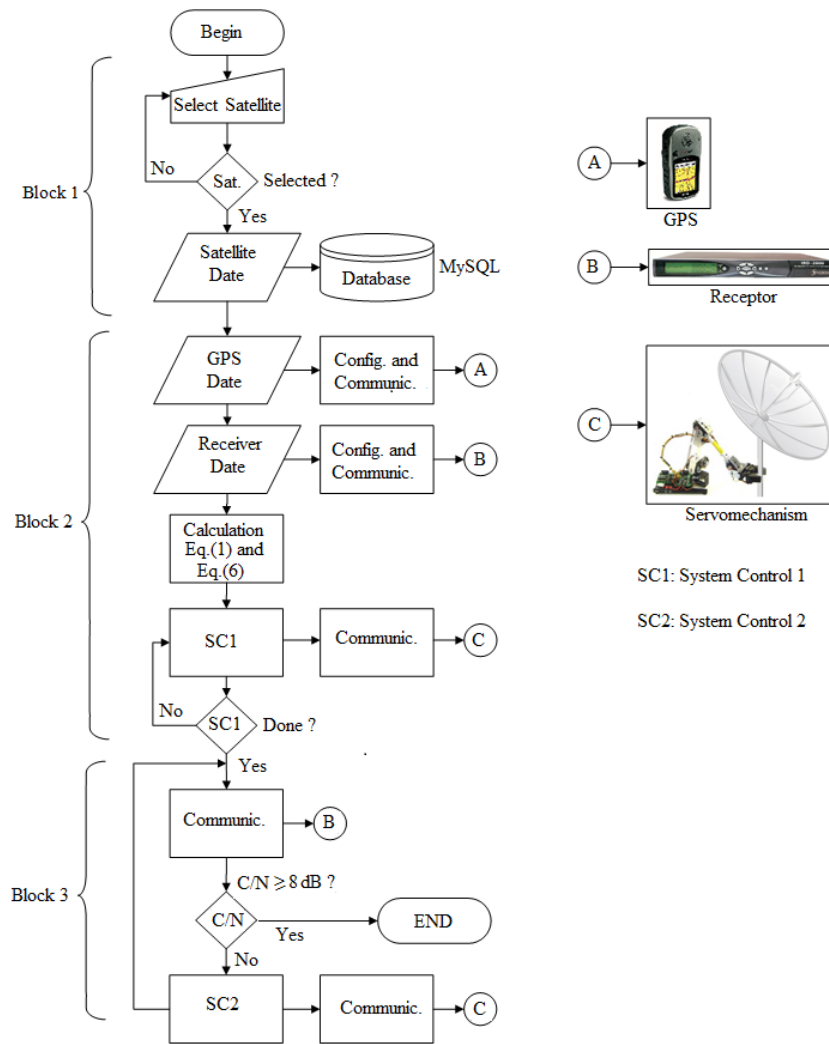


Figure 4 – Automatic maneuvering system.

The S3A system was divided into three blocks, whose functions are:

- **Block 1:** realizes the choice of the desired satellite registered in the database and extracts the data. The system waits for the choice to go to the next step.
- **Block 2:** carries out the configuration of the GPS and of the digital receiver, extracting the latitude, longitude, altitude and C/N in order to calculate the values of elevation and azimuth angles (the reference position to the antenna) and send them to the servomechanism system, using the Control System 1 (SC1). The data obtained from the communication system are: channel, frequency, symbol rate, forward error control, modulation and polarization.
- **Block 3:** performs the management control and a second control (SC2) for moving the antenna, and verifies the quality of the received signal using the C/N ratio provided by the digital receiver. If the value of the C/N is greater than or equal to 8 dB, then the pointing process ends the antenna. In this case, it is used a fuzzy controller which employs 63 rules, generated according to the rules of thumb user in manual maneuvering of the satellite dish.

3.1 Calculation for the reference position to the antenna

The azimuth can be defined as the angular distance measured on the horizon, from a point of origin, clockwise until the vertical circle passing through a given satellite (Maral, 2002).

With the geographic coordinates of satellite and the ground station, the azimuth angle can be derived:

$$\hat{A} = \arctg \left(\frac{\text{tg}|\varphi_s + \varphi_T|}{\text{sen} \theta_T} \right) \quad (1)$$

Where:

- θ_T Latitude of the earth station;
- φ_T Longitude of the earth station;
- φ_s Longitude of the satellite.

For the southern hemisphere with the earth station west of the satellite:

$$A = \hat{A} \quad (2)$$

For the southern hemisphere with the station east of the satellite:

$$A = 360^\circ - \hat{A} \quad (3)$$

For the northern hemisphere with the earth station west of the satellite:

$$A = 180^\circ - \hat{A} \quad (4)$$

For the northern hemisphere with the earth station east of the satellite:

$$A = 180^\circ + \hat{A} \quad (5)$$

The elevation angle is one that exist in the vertical plane between the satellite and earth station antenna. According to Ha (1986), the value of the elevation angle can be obtained from Eq. (6).

$$E = \arctg \left(\frac{r - R_e \cdot \cos \varphi_T \cdot \cos |\varphi_s - \varphi_T|}{R_e \cdot \text{sen} [\arccos (\cos \varphi_T \cdot \cos |\varphi_s - \varphi_T|)]} \right) - \arccos (\cos \varphi_T \cdot \cos |\varphi_s - \varphi_T|) \quad (6)$$

Where:

- r radius of the geostationary orbit [42,164 km];
- R_e radius of the Earth [6,378 km].

4. SYSTEM AUTOMATIC ANTENNA MANEUVERING

The calculation of elevation and azimuth of the antenna requires the location of the satellite and of the earth station antenna. The level of the receiver signal is provided by de receiver decoder.

A set of graphical interfaces allows the user to manage the entire automatic maneuvering antenna, attaching the information on the antenna position and level of desired received signal.

Figure 5 illustrates how the user selects the desired satellite: the system searches the database information for the chosen satellite, using the GPS information, and then computes the values of the elevation and azimuth.



Figure 5 – Main graphical interface

The system performs the calculation of the pointing and configuration of satellite decoder automatically.

The satellite receiver is plugged into the laptop's serial port, allowing it to be automatically configured by the software based on Java platform (Reese, 2000).

The computer performs communication via the serial port RS-232 protocol with the satellite receiver to send the configuration data of the satellite channel and to receive the data signal in a iteration way.

After setting up the receiver, the computer performs the calculation for the antenna placement in a iteration way.

The position of the antenna is obtained from the GPS information that constantly sends to the computer via the serial port. The system monitors the position of the antenna and recalculates the maneuvering, if necessary.

The system with the information about latitude, longitude and the satellite position performs a mathematical calculation to obtain the values of azimuth and elevation angles in order to move the antenna.

After calculation, the system stores data in a database. Also, the system, from the movement of the antenna, evaluates the level of signal-to-noise ratio is ≥ 8 dB.

Thus, the antenna is properly pointed and is receiving a good quality digital signal. If a good quality signal is not achieved, the system automatically performs a second control, using then fuzzy logic (Ross, 1997) to refine the maneuvering.

4.1 Fine tuning

Fine tuning aims to improve the antenna gain of the link “antenna - satellite”, after the dish motion. In adverse conditions, the signal-to-noise ratio can be degraded due to the attenuation by rain, therefore, the importance of the antenna to have the best C/N ratio to ensure the reliability of the link.

Even when the antenna is in a desired position, the C/N ratio can be below the minimum value for a good reception. Consequently, it was necessary to design a control system to solve the problem of fine-tuning the antenna position. Our approach was to use a fuzzy controller which employed 63 rules, generated according to rules of thumb used in the process of manual maneuvering a satellite dish.

For the project, were considered two inputs, the first is the received signal (signal-to-noise ratio) and the second is the variation of the error of the received signal. The output was the control signal for the fine motion of the antenna, in degrees.

In this work we used a Mamdani type inference (Mendel, 1995).

Figure 6 illustrates the implementation of the system, using the software Matlab ® Fuzzy Logic Toolbox.

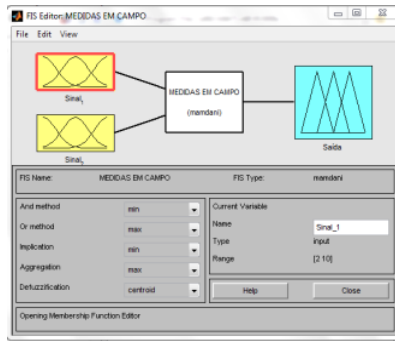


Figure 6 – Matlab® Fuzzy Logic Toolbox

For mapping the physical variables to the set of fuzzy linguistic variables, the triangular function was chosen since fact the method of maximum average defuzzification was chosen.

Table 1 shows the seven membership functions for variable received signal and their limits.

Table 1 – Standardization of input 1.

Input 1	S1	S2	S3	S4	S5	S6	S7
Lower	2	3	4	5	6	7	8
Peak	3	4	5	6	7	8	9
high	4	5	6	7	8	9	10

Data in Table1 is implemented using a triangular function, as shown in Figure 7.

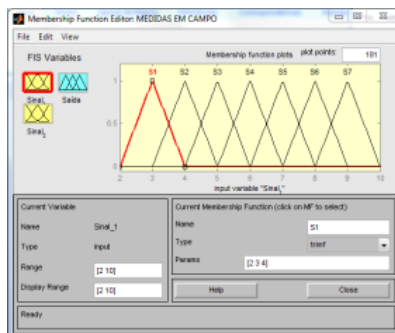


Figure 7 – Relevance functions of the normalized signal reception

The second input corresponds to the track error received signal, which should remain between -0.8 to 0.8 dB. Table 2 presents the second input that has nine relevance functions.

Table 2 – Normalization of input 2

Input 2	-EG	-EM	-EP	-E	E	+E	+EP	+EM	+EG
Lower	-1	-1	-1	-0	-0	0	0,2	0,4	0,6
Peak	-1	-1	-0	-0	0	0,2	0,4	0,6	0,8
high	-1	-0	-0	0	0,2	0,4	0,6	0,8	1

Data in Table 2 are implemented using the triangular function, as shown in Figure 8.

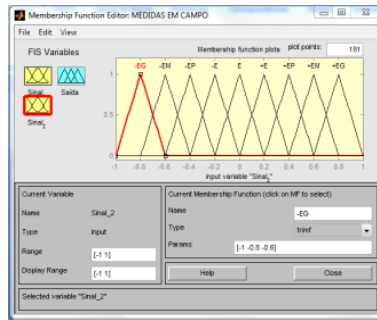


Figure 8 – Relevance functions of the standard error of the received signal.

Table 3 and Figure 9 show the limits of the relevant output. The direction of movement of the antenna will be positive for clockwise motion and negative for counterclockwise.

Table 3 – Normalization of output.

Output	-R6	-R5	-R4	-R3	-R2	-R1	R	R1	R2	R3	R4	R5	R6
Lower	-6	-5	-4	-3	-2	-1,25	-0,5	0	0,5	1,25	2	3	4
Peak	-5	-4	-3	-2	-1,25	-0,5	0	0,5	1,25	2	3	4	5
high	-4	-3	-2	-1,25	-0,5	0	0,5	1,25	2	3	4	5	6

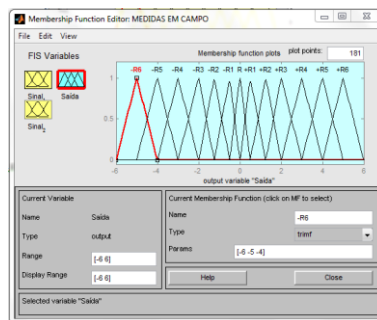


Figure 9 – Normalized relevance functions of the control signal.

From the input and output linguistic variables and from the configuration of their relevance functions, 63 rules were developed, as shown in Table 4.

Table 4 – Block of fuzzy rules

	-EG	-EM	-EP	-E	E	+E	+EP	+M	+EG
S1	-R6	-R6	-R6	-R6	+R6	+R6	+R6	+R6	+R6
S2	-R5	-R5	-R5	-R5	+R5	+R5	+R5	+R5	+R5
S3	-R4	-R4	-R4	-R4	+R4	+R4	+R4	+R4	+R4
S4	-R3	-R3	-R3	-R3	+R3	+R3	+R3	+R3	+R3
S5	-R2	-R2	-R2	-R2	+R2	+R2	+R2	+R2	+R2
S6	-R1	-R1	-R1	-R1	+R1	+R1	+R1	+R1	+R1
S7	R	R	R	R	R	R	R	R	R

Figure 10 illustrates the implementation of the block of fuzzy rules, according to Table 4.

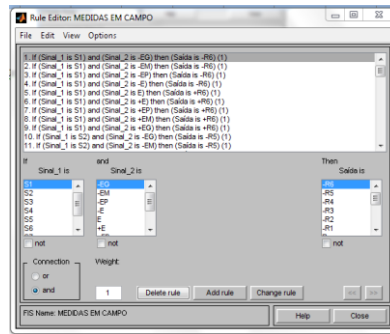


Figure 10 – Block of rules

Below are some examples of the implementation of the block of fuzzy rules:

- * If (Input_1 is S1) and (Input_2 is -EG) then (Output is -R6)
- * If (Input_1 is S2) and (Input_2 is -EM) then (Output is -R5)
- * If (Input_1 is S3) and (Input_2 is -EG) then (Output is -R4)

5. VALIDATION OF THE EXPERIMENT

The validation experiment was performed in Santa Cruz farm, in Cachoeira Paulista -SP, using a receiving antenna with a 3.2 m diameter parabolic reflector.

We added to the platform an antenna, a GPS to monitor the same spatial location, and a digital receiver, which provides the C/N. Our Control System Antenna Maneuvering, S3A, processed the information of the spatial position of the antenna, generating a reference signal for a servo (not treated in this work). After processed, if the C/N was not adequate, the system performed a fine antenna positioning to improve the received signal.

Given that K represents the time instant, the input data S_K are obtained directly from the receiver. The error data E_{K+1} are calculated by $E_{K+1} = S_{K+1} - S_K$, and the values of the movement of the antenna are obtained from the response of the fuzzy method.

Table 5 represents the results obtained in the field, by moving the antenna. When the values of the signal increased, the corresponding motion values of the antenna decreased.

Table 5 – Results obtained from experience and testing of the measures in the field.

K	Movimento da Antena	S_K, dB	E_{K+1}, dB
0	-	5.37	-
1	1.00° Right	5.95	0.58
2	1.81° Righth	6.35	0.38
3	1.34° Righth	6.94	0.59
4	0.93° Righth	7.58	0.64
5	0.97° Left	7.50	-0.80
6	0.52° Righth	8.44	0.90

6. CONCLUSION

The results proved to be very good.

Based on the manual pointing we could generate all the architecture control system and create a simple and fully operational Control System Antenna Maneuvering (S3A).

An efficient fuzzy controller was developed, with 63 rules to interpret human knowledge during the pointing.

The manual procedure takes about 50 minutes to align the antenna until it find the level of C/N required (≥ 8 dB). In the manual procedure is not always found the value of the $C/N > 8$ dB, due to having a large number of exhausting attempts so obtain a value close to that.

With our system the alignment took only about 3 min to be successfully completed, it was found at a C/N of 8.44 dB.

This response of the C/N ratio was obtained starting from 6 attempts of the system until it reaches the desired value.

So, we can conclude that the results obtained from the experiments validated the system S3A and our automation goals were completely achieved.

7. REFERENCES

- Chang-Ho, Sang-hyo, T., Y. “Antenna control system using step tracking algorithm with h controller”. International Journal of control automation and system, v. 1, p. 1, March 2003.
- Date, C. J., 2004. “Introdução a Sistemas de Banco de Dados”. Rio de Janeiro, Afiliada.
- Elmasri, R. E. . N. S.,2005. “Sistema de Bando de Dados”. São Paulo, Pearson.
- Esteves, L. C. Antenas: teoria e aplicações. [S.l.]: Mac Graw Hill do Brasil, 1980.
- Franco, M. Y.,2004. “Universidade Java. Ambiente de Desenvolvimento Java”. Afiliada.
- Ha, T. T.,1986. “Digital Satellite Communications”. Macmillan Publishing Comp.
- Jongkwon, Kyeumrae J., Cheolsoo, T. “Simplified fuzzy PID controller of data link antenna system for moving vehicles”. Lecture Notes in Computer Science, Berlin, v. 4099, p. 1083-1088, 2006.
- Maral, G.; Bousquet, M., 2002. “Satellite Communications Systems: Systems, Techniques and Technology”, John Wiley & Sons, Inc.
- Mendel, J. M., 1995. Proceedings of the IEEE. In: “Fuzzy Logic Systems for Engineering”. McGraw-Hill, v. 83, Cap. 3, p. 345-377.
- Nunes, M. A. S.,1986. “Telecomunicações IV”. CDT - INATEL.
- Reese, G., 2000. “Database Programming with JDBC and Java”. O`Reilly.
- Ross, T. J., 1997. “Fuzzy Logic with Engineering Applications”. McGraw-Hill.